Full Play: A Modern Record Player

Final Report

24-671: Electro-Mechanical Systems Design

May 11, 2018

Group Members: Mehar Singh, Rodrigo Royo, Jack Kasbeer, William Boyajian, Edward Holthaus
Group Name: Full Play (FP)

We hereby acknowledge that all of the following members worked on this report:

1. Executive Summary

Most record players utilize designs that haven't been changed since the 1980s. While these designs capture the unique sound quality associated with vinyl record players, they lack the convenience and features that newer music medias. Our Full Play turntable aims to solve two of the most intrinsic problems of vinyl records by allowing users to listen to both sides of the record without any interaction and adding newer technologies to the antiquated designs. Attempting to aid and facilitate a newer generation of vinyl listeners. The flipping assembly will be mounted on a signature "globe" design, consisting of one vertical ring and one horizontal ring. This design provides room for the record flip, and gives the product a unique look that will make a statement in any user's home. Our final prototype should be a device that can autonomously play and flip a record, returning to its original position once complete. The device should do so "out of the box" ready to be placed on the users table top, or as a flashy centerpiece to any room. Our final deliverable will be a complete turntable system, that will be wired to a speaker at the final expo. We aim to complete this project within one semester.

2. Problem Definition

2.1 Problem Description

Vinyl turntables are an antiquated medium for playing music. They lack the usability of newer technologies, specifically modern digital media. Vinyl albums must be played all the way through. The entire album is split onto two sides of the record, forcing users to manually stand up and flip the record to complete the experience. Our goal is to create a mechatronic system to solve this problem.

Despite being an old technology, there has been a massive resurgence in the popularity of turntables over the last decade, as shown in Figure 1. Turntables have now become a must have for any devoted music aficionado.

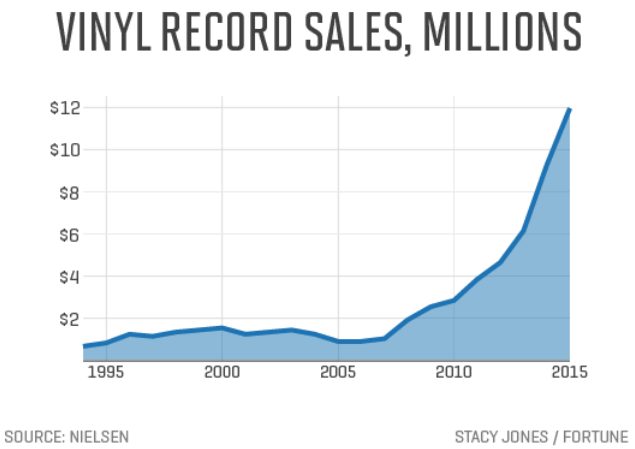


Figure 1 - Historical Vinyl Record Sales[1]

The resurgence of vinyl shows that consumers still seek out tactile products that provide a physical satisfaction with purchase. It is widely accepted that vinyl, even high quality 180 gram pressings, are much lower in sound quality than modern uncompressed digital recordings. However, vinyl records provide a physical culture that allows users to go to a store and flip through a rich history of music in search for the perfect record or a rare find that can go up on the mantelpiece. This pushback shows that even in the digital age nostalgia and small business can still play a huge role in consumers decisions. This nostalgia has primarily been the force behind the popularity and spike in sales for vinyl. In addition to buying records, devoted users typically pay hundreds of dollars for high quality needles, tonearms and materials, spending hours every week looking for the right records. It is a whole industry that is still alive, with a huge market for products.

[1] https://www.planetofsoundonline.com/pages/yes-turntables-are-back



Figure 2 - Jerry's Records: a local record shop in Pittsburgh

The aim of our robotic turntable is to solve two of the most intrinsic problems of vinyl records by allowing users to listen to both sides of the record without any interaction and adding newer technologies to the antiquated designs. Our system will allow users to enjoy a full album, as it was intended, without having to exert any effort in flipping the record. A user would simply place their record into the "Full-Play" system, clamp it down and press play. The device will play through the first side, move the needle out of the way, flip the record, then continue playing. Once the album is complete the device will return to its original position and the user can either insert a different record or lock the needle into place for storage.

The "Full-Play", like most turntables, is both a practical music playback device, as well as a statement piece in the user's room. It must have simple user interactions while being aesthetically pleasing and attractive. We seek to take record players from the corner of users rooms and make them the centerpiece of people's rooms. The "Full-Play" will be a conversation starter that will set the mood in the room. It will be perfect for offices, bedrooms and living rooms. We hope to bring new users into the vinyl world by providing them a luxurious device, for an affordable price.

2.2 Markets Addressed and Primary Competitors

The primary market we are attempting to address are new vinyl record users who want the ease of modern music, but enjoy the tactile nature of physical media. Our secondary market is the older generations of vinyl users, who may want to continue using their original records without having to get up every 20 minutes. This market is still growing and lacks a product like the "Full-Play" which would allow users to save time and increase enjoyment. As mentioned before record sales have skyrocketed in the last decade and thousands of independent record shops remain active around the country. If we provide the perfect luxury entry level turntable we can facilitate new users into supporting these local businesses while providing a unique and tactile listening experience.

There have been several attempts in past decades to build a turntable that can play both sides of the vinyl record. These designs began as bulky cabinet set, that used pulleys and counterweights to flip the record. However for a brief moment in the 80's many of the world's leading music tech companies experimented with this novel idea. We focused on two of these designs as the main competitors to our product, since they attempted to target improving the ease of use of vinyl record players.

One example was the Sharp VZ. (Fig. 3) which solved the problem of playing on both sides by vertically holding the record. The VZ was an all in one boombox system, where the record was placed into a tray much like a cassette. However, it came with a price tag of $800 and a very inelegant and unappealing solution that looks more like a stereo than a turntable. The VZ had no real market success and disappeared with much of the dual sided fad of the 80's

The Technics SL-QL14 (Fig. 4) implemented a linear tracking approach - which moved the needle linearly across the record. This technology could be utilized to place the needle at the desired position of specified songs. This improved the ease of use and added newer technologies to select specific songs within the record. However, this device resulted in poor audio quality due to vibrations caused by the servo in the tracking arm making it an unreliable solution.



Figure 3 - Sharp VZ Record Player



Figure 4 - Technics SL-QL14 Record Player

In recent years U-Turn has attempted to create a product for our same "new-user" market. Their turntables claim to be entry level with "audiophile" quality. Their products range from $180-$400 and use industry standard components. They however have not added any new features, focusing on the simplicity of vinyl, using a belt drive motor and standard uncontrolled needle. We want to have a product that is priced competitively with U-Turn, but hope to beat them out by providing the "Full Play" functionality. We see the U-Turn as our main competitor in the new market.



Figure 5 - The U-Turn "Orbit"

Our primary competitors have attempted to implement solutions that utilize newer technologies and can play both sides of the record player. However, due to their inelegant solutions and high price tags, have been unable to penetrate the market. Most other turntables in the market utilize designs that have not been changed or developed since the 1980s. Our turntable attempts to create an elegant and relatively low-priced solution that can implement newer technologies, playing both sides of the record. We are targeting the "wow" factor of this feature as our main selling point.

2.3 Assumptions and Constraints

Our major constraints for this project are indicated below:

1. Budget - $750
2. Size - Our system should be a similar size to that of a standard turntable and no larger than 20 x 20 x 20 inches
3. Complexity - We should implement a solution that is as simple and elegant as possible to maintain the aesthetic of turntables
4. Time - We must complete our project within the allotted 1 semester timeline

3. Stakeholders and Customer Needs

3.1 Stakeholder Identification

To identify our stakeholders or those who are affected by our product, we conducted a brainstorming process to collect an exhaustive list of individuals and groups by asking ourselves who are the individuals or groups that are interested in our product, who are the potential beneficiaries and who are negatively impacted.

Table 1 below shows our list of stakeholders organized into 3 categories - primary, secondary and tertiary

Primary	Secondary	Tertiary
Turntable Users / Owners	Suppliers	Record Artists
Manufacturers	Record Store Owners	Vinyl Industry
	Competitors	
	Retailers / Wholesalers	

Table 1 - Stakeholder Identification

We can see that our end users of the turntable and manufactures are our primary stakeholders and our secondary stakeholders include all of our intermediaries in the process of delivering the end product. Our tertiary stakeholders include external factors and decision makers that can influence the turntable industry as a whole that can affect the sales of our product. Thus, our next step was to determine our primary stakeholders' interests - namely the end users to better design our product.

3.2 Customer Needs

In order to conduct an external outreach, we sent out a survey. The survey was sent out to several CMU student facebook pages and to a WRCT mailing list. WRCT is the CMU radio station, where there are several DJ's who play music primarily on vinyl. We reached out to them in hopes to get opinions from the higher end users that define our secondary market. We received 33 responses to our survey within a few days. Of our respondents, a large majority (approximately 80%) owned a turntable and on average listened to about 15% of their music on Vinyl. However, we noticed some interesting responses that countered some of our own in our internal generation that are listed below:

- Less than 25% of the people owned a customized turntable
- Most people stated that song selection was against the point of listening to Vinyl and liked to listen to the whole album in one sitting
- The audio quality was largely subjective

We also internally developed some customer needs that the system must be able to fulfill. Therefore, from the survey and our internal generation activities, we developed the following customer requirements and needs that our product must be able to address and fulfill:

1. The system must not scratch the record
2. The record must not be damaged or warped during the flip
3. It should be easy to place the record into the turntable
4. The system must not be too large
5. Flip should not take too long
6. The system must be aesthetically pleasing and have a classy finish.

Table 2 illustrates these customer requirements and their relative importance. The scale of 1-5 is used, where 5 indicates it is the most important requirement and 1 indicates it is the least important. We determined these importances by summing up the number of survey respondents that indicated the issue as well as own generation of the issues

Need #	Importance
1, 2	5
3	1
4	2
5	3
6	4

Table 2 - Relative Importance of Customer Needs

4. Target Specifications

4.1 Mapping Customer Needs

Our next step was to map each of our customer needs to a concrete value. First, the system should not scratch the record. This is very important, so we aim for our design to never scratch a record. Second, the record must not be damaged during the flip. This would include scratches from the record hitting something or warping if the flipping does not work right. Again, we aim for zero scratching or warping. Third, it should be easy to place the record in the turntable. We mapped this to a specific time based on how long it typically takes to place a record on a turntable. We chose two seconds as the minimum time we thought this would take on a normal turntable, and ten seconds as the maximum time we would allow

for our product. Fourth, we wanted our turntable to not be too large, so that it could easily sit on users desk. We decided that it should fit inside a one to two foot cube. Fifth, we wanted the flip to not take too long, so that there would be good continuity between the two sides of the record. We chose five seconds as are target value, as we need to move the needle arm, flip the record, and replace the needle arm. Finally, the aesthetic design is purely subjective.

4.2 Competitive Analysis

Our goal is to match the performance of competitive products in each category, but with the bonus of the process being automated. For a typical high quality turntable, it will not scratch or damage the record. However, many lower quality turntables will. Not damaging the record is the most important requirement for us. The time taken to place the record on a turntable is fairly quick, likely only a few seconds. Typical turntables tend to be somewhere around 1.5 x 1 x 0.5 feet. The record can be flipped fairly quickly, around five seconds, but the user also has to interrupt what they are doing to walk over and flip it. Finally, most turntables are designed to sit out in a room and be aesthetically pleasing.

4.3 Target Specifications

We specified our customer requirements into key technical and target specifications that our design must meet in Table 3 below. Our marginal value is the minimum requirement that the design must meet and our ideal value is our goal for the design to meet.

Metric #	Need #	Metric	Importance	Units	Marginal Value	Ideal Value
1	4	Unit size	High	Inches	20” x 20” x 20”	16” x 16” x 16”
2	5	Flip time	High	Seconds	20 s	5 s
3	6	Aesthetic Design	Medium	Subjective		
4	3	Time taken to place Record	Medium	Seconds	10 s	2 s
5	1, 2	Visible or Audible damage to Record	Highest	# of scratches	0	0

Table 3 - Target Specifications

5. Concept Generation

5.1 Functional Decomposition

The diagram below illustrates our functional decomposition. It details all of the core tasks that the final prototype must complete and how they interact with one another. The boxes in red highlight the high level primary functions that we must complete. The green boxes indicate the technology already exists to implement these functions and we can buy off-the-shelf parts to accommodate them. Lastly, the blue boxes indicate the main focus of our product and the newer features that we are implementing and need to spend a majority of our time implementing and refining.

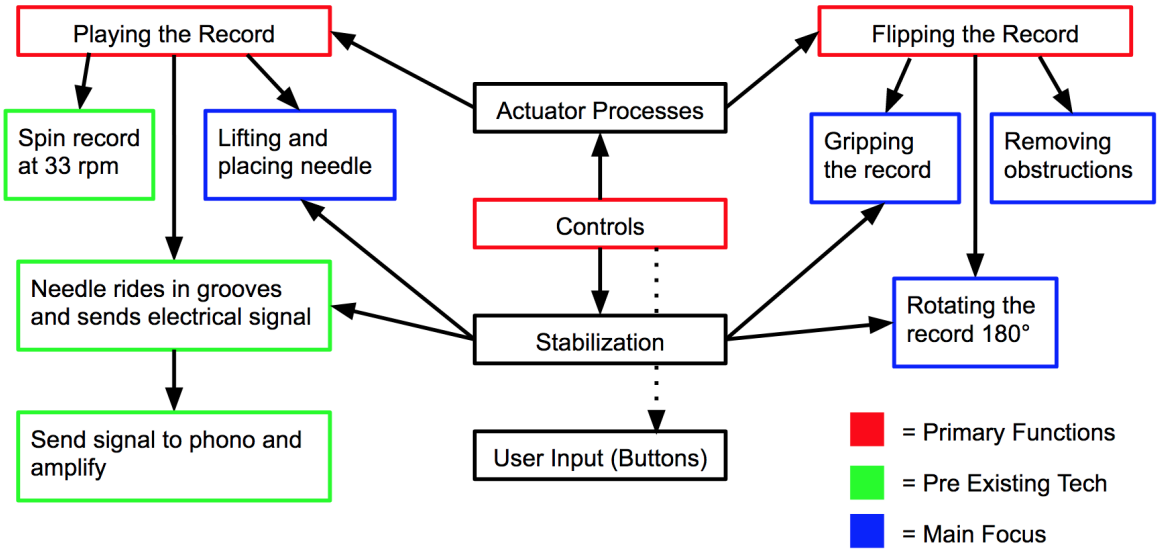


Figure 6 - Function Decomposition and State Chart of System

5.2 Concept Generation

We then interpreted our functional decomposition into six main sub functions. These were the record spinning method, the needle mechanism, the flipping mechanism, the microcontroller, the actuators, and the position tracking. As the latter three of these are electronic related, we did not do any sketching for them. Below is some of our concept generation for the other three subsystems. For our concept generations for our subsystems, we looked into some existing technologies utilized in turntables and made minor adjustments to accommodate our purpose as well as came up with some internally generated concepts.

Record Spinning Mechanism

For this concept, we require a motor that can rotate the record at a constant velocity of 33rpm. Some of the different concepts we came up with are shown below:

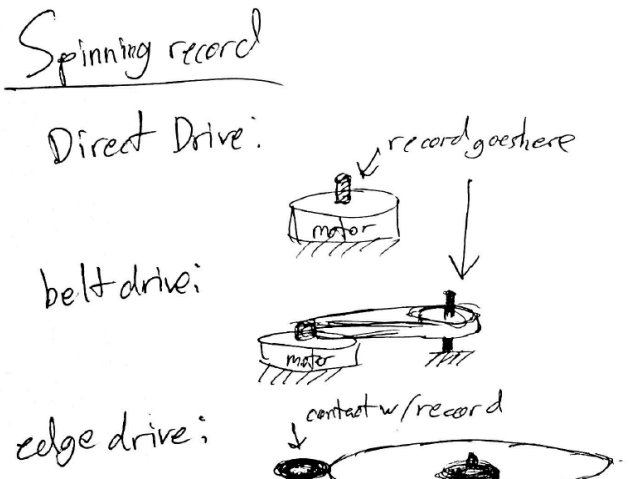


Figure 7 - Spinning Mechanisms Sketch

Needle Mechanism

In this concept, we require the needle to be positioned on the record manually but autonomously removed from the record once the side of the LP has finished. Our concept generation activities, both internal and external, came up with the following designs.

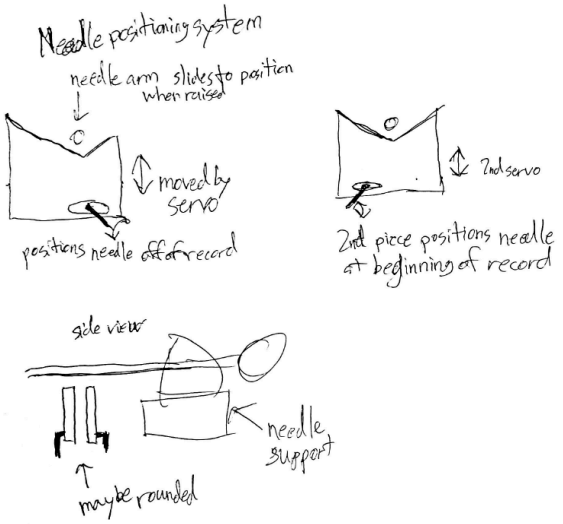


Figure 8 - Needle Mechanism Sketch

Flipping Mechanism

In our flipping mechanism, we required a method to flip the record 180 degrees in order to play on the other side of the record autonomously. Some of the mechanisms we came up with are shown below. Each method will be used alongside a PID Controller to make sure the flip is consistently and reliably 180 degrees.

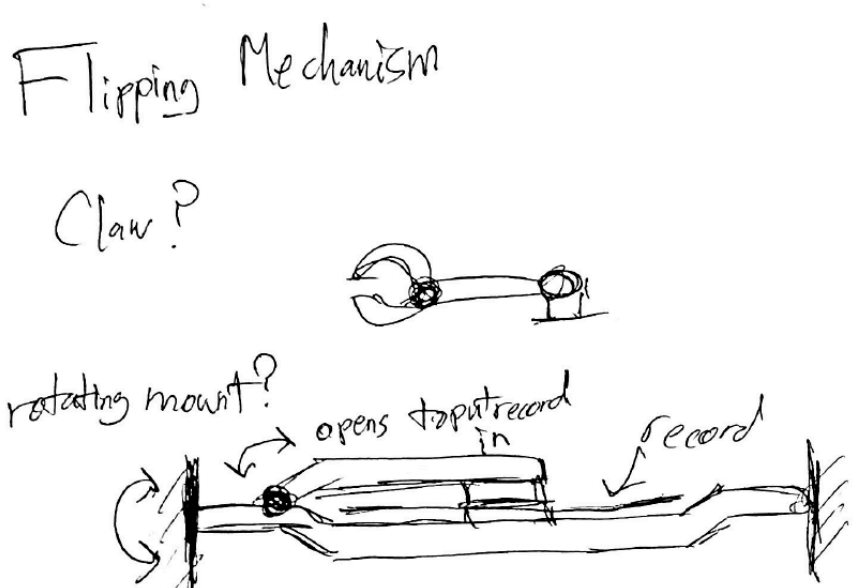


Figure 9 - Potential Flipping Mechanisms Sketch

5.3 Classification and Combinations

We narrowed down some of our concepts for each of our main sub-functions into Table 3 shown below. We based these on concepts that were feasible to implement given our time and budget constraints as well as focussing on different key designs that would affect the design of the product.

SUB-FUNCTIONS					
Record Spinning	**Needle**	**Flip**	**Microcontroller**	**Actuators**	**Position Tracking**
Direct Drive	Rotational	Lift and Flip	Arduino	Pneumatic	Line Tracker
Belt Driven	Linear Tracking	In Plane	Rasberry Pi	Servos	Camera / Computer Vision
Edge Drive		Double Tracking	Photon	Stepper Motors	Motor Encoders

Concept	Color
A	
B	
C	

Table 4 - Combinations of Concepts

Based on the key concepts for each sub-function, we generated 3 overall combinations for our overall design. These designs are highlighted and color-coded according to the table above. Each concept is shown and described below.

Concept A

Our first design is a simple robotic mimicking of the flipping that a user would typically do. Essentially, once the first side has finished, one or multiple arms will lift the record high enough that it will not interfere with any part of the turntable, flip it 180 degrees, and lower it back down into place so that the second side can begin. This is likely the most intuitive design. It would also allow us to reuse the majority of an existing turntable. However, it would also be fairly complex to program such a complicated and precise movement for the flipping arms. Additionally, if something were to go wrong, it could result in damage to the record.

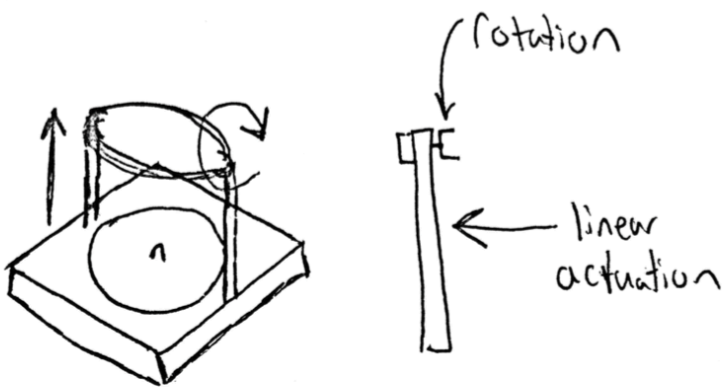


Figure 10 - Concept A: 'Lift and Flip'

Concept B

Our second design is a variation on the linear tracking technology used in some competitive products. This features a needle that slides on a rail. As the record plays, the needle will slide toward the center of the record. Our concept is to extend this to both sides of the record by putting a second needle on the bottom, facing up. When ready to play the second side, the first needle would lift, the second needle would rise, and the record would reverse direction. This would eliminate the need for any flipping and would be a very fast switch. However, this system can prove finicky, and using it for both sides of the record could be very difficult. Getting the needle pressure right on the upward facing issue would likely be the primary issue, and the sound quality would likely suffer.

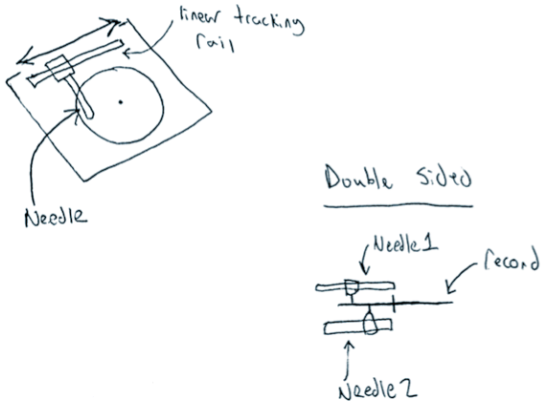


Figure 11 - Concept B: 'Linear Tracking'

Concept C

Our third design features the record suspended in the air by two rings, similar to a globe. The first ring is vertical and attaches to a sturdy base at the bottom. The second ring is horizontal and attaches halfway up the first ring. The record is held in plane with this horizontal ring by two arms that snap together, fixing it in place. These arms can flip, allowing the record to flip in plane so that the second side can be played. The needle attaches to the horizontal ring and swings out over the record. This idea provides a unique design and a simple and quick flip. However, we would have to make sure that the alignment of the record is always perfect, and that it is well supported. Additionally, this would allow us to take the least from an existing turntable.

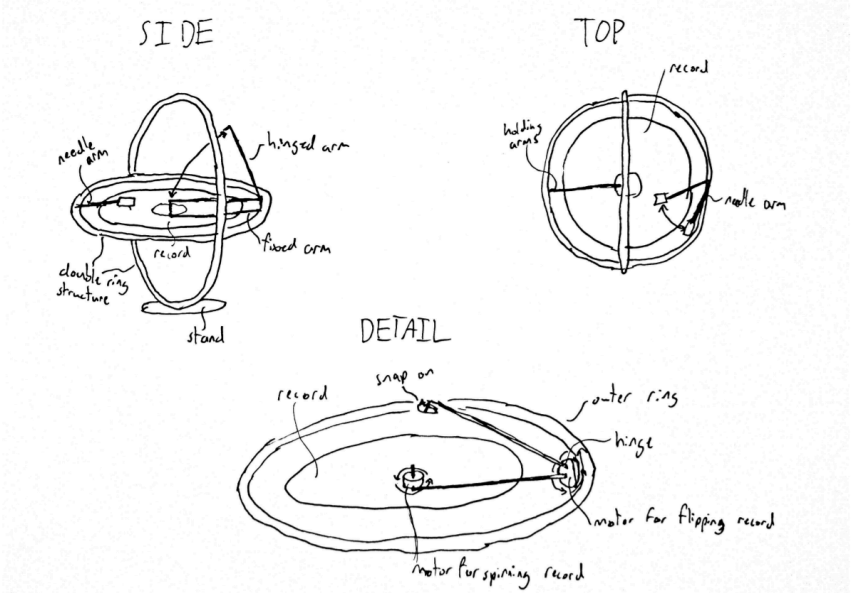


Figure 12 - Concept C: 'The Globe'

6. Concept Selection

6.1 Concept Selection Process

Our concept selection process consisted to two benchmarking and analysis matrices. Firstly, we created our baseline of the Sharp VZ turntable (as discussed in Section 2.2). We then created a Pugh matrix to determine how each of our concepts measured against our baseline shown below.

The score of 0 indicates that the concept roughly is the same as our baseline in that component and +1 and -1 shows that the design is better or worse than our baseline respectively in that category.

Selection Criteria / Decision Factors	Baseline - Sharp VZ	Concept A - Lift & Flip	Concept B - Tracking	Concept C - Globe
Criteria	1	2	3	4
Support on Record	0	1	1	0
Ease of Flipping the Record	0	0	1	1
Audio Quality	0	1	1	-1
Placement of Record	0	1	1	1
Time taken to Flip Record	0	0	1	1
Size	0	0	0	-1
Safety of Record	0	0	0	1
"Wow" Factor	0	1	0	1

Table 5 - Pugh Matrix

Once we created the Pugh matrix, we found that all of our concepts significantly beat our baseline competitor of the Sharp VZ. Thus, we decided to keep all of these designs and move them on into the next phase of the Selection matrix. In this matrix, we assigned weights to each of the selection criteria.

In the selection matrix, our scale was modified into a 1, 3 and 5 scale - where 3 was set as our baseline. Thus, our baseline model contained all 3's in the categories and the score of 1 indicated the design was worse than our baseline and 5 meant it was significantly better than our baseline for each selection criteria. Our selection matrix is shown below in Table 5.

Selection Criteria / Decision Factors		**Baseline - Sharp VZ**	**Concept A - Lift & Flip**	**Concept B - Tracking**	**Concept C - Globe**
Criteria	**Weight**	**1**	**2**	**3**	**4**
Support on Record	5	3	5	5	3
Ease of Flipping the Record	3	3	3	3	5
Audio Quality	4	3	3	3	3
Placement of Record	2	3	3	3	3
Time taken to Flip Record	4	3	1	5	3
Size	3	3	3	3	1
Safety of Record	5	3	3	3	5
"Wow" Factor	2	3	3	1	5
Cost	2	3	3	1	5
Aesthetic Design	3	3	3	3	5
Score		99.0	101.0	109.0	**126.0**
Rank		-	3rd	2nd	**1st**
Verdict		-	Pass	Pass	Keep

Table 6 - Selection Matrix

From our selection matrix, we saw that Concept C had the highest score by a large amount. Therefore, we decided to move forward with Concept C for the design of our project as it met and exceeded the customer requirements and other selection criteria in our matrix.

6.2 Assessment and Justification

Based on the selection and Pugh matrices, our choice was fairly clear. The Globe design won the selection matrix by a large margin. It is by far the best looking, making it a good choice. It also met all of our other requirements, meaning it will fulfill its function of flipping the record properly. While it is the largest of the three designs, we feel that its aesthetics make up for that, as it will be a centerpiece on whatever furniture it is placed on.

6.3 CAD Model of Concept

Figure 13 depicts our CAD Model of our design. It will be a 'Globe' design consisting of 2 rings - a horizontal ring that will provide the rotational axis for the flip and a vertical ring that will provide support for the entire system. The system also contains two arms: a bottom arm that can rotate within the horizontal ring that holds the record and the motor and a top arm that clamps down on the record for support.

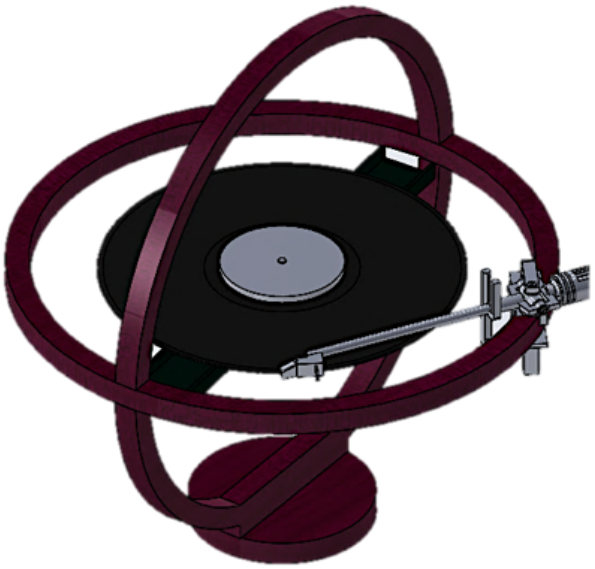


Figure 13 - Overall CAD Model of the System

Other views such as the Side View and Flipped View of the CAD Model are shown in the Appendix below.

7. Concept Description

7.1 Concept Design

Our concept design features the record suspended in the air by two rings, similar to a globe. The first ring is vertical and attaches to a sturdy base at the bottom. The second ring is horizontal and attaches halfway up the first ring. The record is held in plane with this horizontal ring by two arms that snap together, fixing it in place. These arms can flip, allowing the record to flip in plane so that the second side can be played. The needle attaches to the horizontal ring and swings out over the record. This idea provides a unique design and a simple and quick flip. However, we would have to make sure that the alignment of the record is always perfect, and that it is well supported. Additionally, this would allow us to take the least from an existing turntable.

7.2 CAD Model of Concept

Figure 13 (above) depicts our CAD Model of our design. It will be a 'Globe' design consisting of 2 rings - a horizontal ring that will provide the rotational axis for the flip and a vertical ring that will provide support for the entire system. The system also contains two arms: a bottom arm that can rotate within the horizontal ring that holds the record and the motor and a top arm that clamps down on the record for support. Other views such as the Side View and Top View of the CAD Model are shown in the Appendix below.

From our Prototype I and II, our concept design did not heavily change. However, our subsystems changed a little primarily due to the manufacturability of the components as well as the integration with other parts of the design.

7.3 Electrical Schematic and State Machine

Our electrical schematic illustrate the communications between our Arduino Mega and the various motors and components in our design is shown below. The Arduino Mega takes an input of 12V from our wall power source. There is a Adafruit motor shield on our controller that has a max current draw of 1.2A. The Arduino Mega will control the various motors used for our needle mechanism as well as flipping and spinning the record.

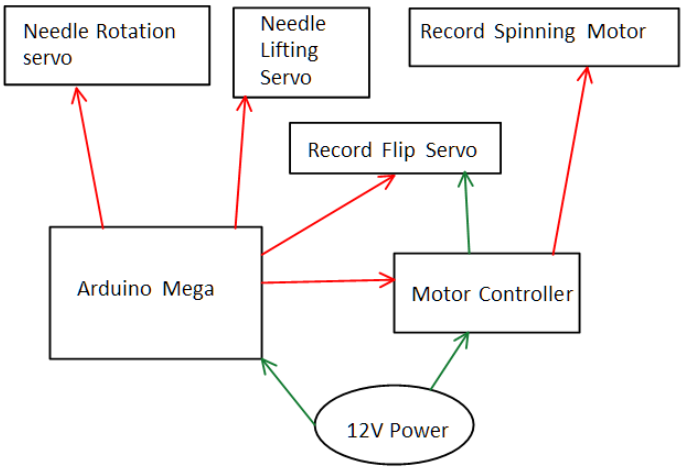


Figure 14 - Electrical Schematic

Our state machine illustrates and represents how our code functions and sequential tasks that the design will undertake.

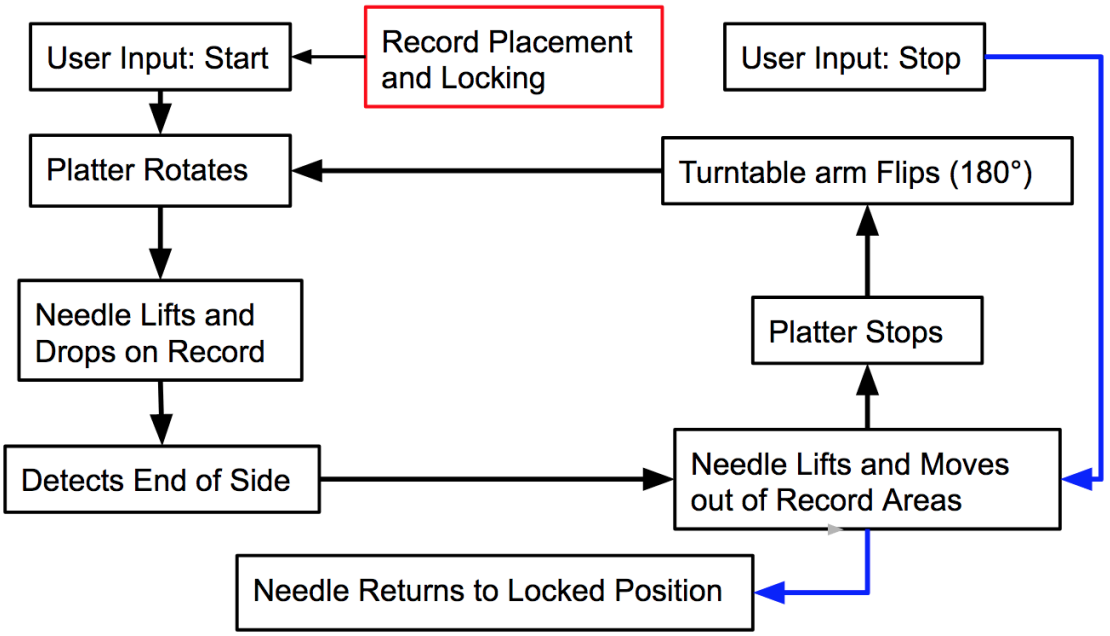


Figure 15 - State Machine

Our device has 4 main states: Platter spinning, Platter Stopped, Flipped and Unflipped. The states flow through each other as the entire record is played. The device will follow the flow shown above until two sides have been, returning to its locked position.

8. Detailed Design and Engineering Analysis

8.1 Needle Positioning Assembly:

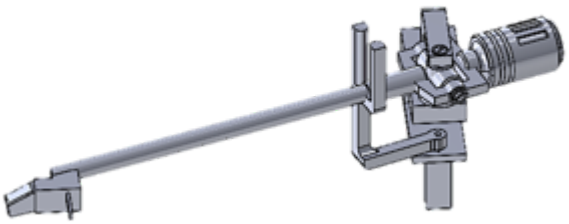


Figure 16 - Needle Positioning Assembly concept

The needle positioning assembly is responsible for raising and lowering the needle, as well as changing its angular position. This will require the usage of two actuators, one to raise and lower the needle, and the other to change the angular position. The concept mechanism uses one servo and one DC motor to accomplish this. The servo raises and lowers the needle by pushing against the counter-weight located at the back of the needle. It rotates a 3D-printed piece to push the counterweight down to lift the needle and then slowly releases to lower the needle onto the record or back to its resting location. The DC motor is connect to the shaft that holds the needle and rotates the needle into place. We utilized a DC motor with encoder that will allow us to use a PID controller to tune the values to minimize the error with placing the needle.

To select the servo, we calculated the torque needed to raise and lower the assembly, since the amount of torque needed to rotate the needle will be minimal. For the servo responsible for raising and lowering the needle, the weight of the assembly and the downward force of the needle must be accounted for. The servo weight is approximately 6g, and the estimated weight of 3D printed hardware, screws, etc is 50g. The needle exerts the same force as a 3g mass at the end of the arm by design. Since we are raising the needle from 1/5 the way from the end, that equates to a 15g mass force thanks to the mechanical advantage of 0.2. The servo has a maximum torque of 1.2 kg*cm at 4.8V, and the length of the servo horn is 1.25cm. This servo will be lifting mass in the vertical direction, so kgf can be used. Thus the torque requirement: (0.006kg + 0.05kg + 0.015kg) * 1.25cm = 0.089 kg*cm. The FoS with this design is 1.2 / 0.089, which is approximately 13.5. Thus the servos we selected are plenty strong enough.

8.2 Record Deflection Analysis

When music is being played, the needle puts three grams of mass on the record. We were concerned that this force would deflect the record enough to lower the sound quality, especially on the first few songs when the needle is further from the center of the record. If the dip in quality is noticeable, we will have to program our motor to rotate the record slightly depending on the position of the needle on the record. We ran calculations to see how significant the deflection would be when at the outermost part of the record. Our full hand calculations are in the appendix.

$$\delta(x) = \int \theta(x)\, dx$$

$$\theta(x) = \int \frac{M(x)}{EI(x)} dx$$

$$M(x) = (L - x) * m * g$$

Where L is the distance from the edge of the platter to the edge of the record, d is the distance from the center of the record to the edge of the platter, r is the radius of the record, x is the distance from the edge of the platter to the needle, h is the thickness of the record, m is the mass of the needle, and g is gravity.

By performing this double integration, we found this maximum deflection to be 0.0178 inches. This means that if we wanted to account for this deflection, our motor would need to rotate 0.28 degrees. We think that it is unlikely that this slight deflection is something that would affect sound quality. However, if we find in testing that it does, we will need to program in this rotation.

We also ran a deflection analysis in Solidworks to see how that compared

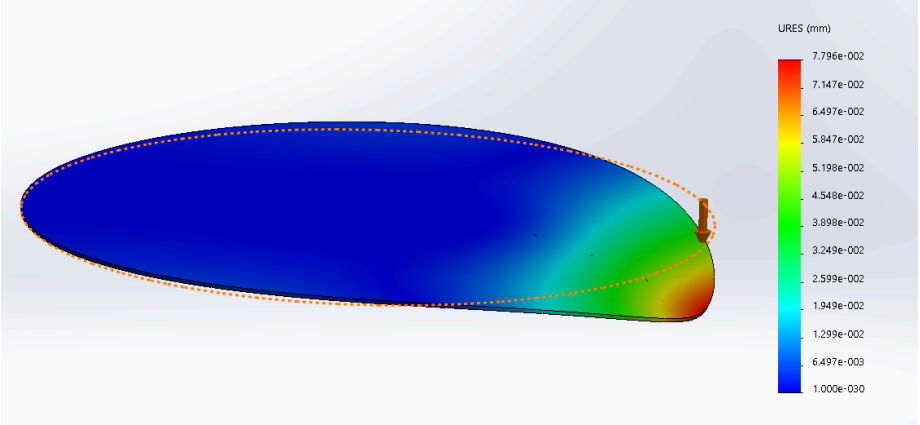


Figure 17 - SolidWorks Deflection Simulation

The resulting deflections were noticeably lower than with hand calculations, meaning the change to sound quality could be even more negligible. Below is a table of deflections at the needle location when the needle is at different points on the record.

Needle distance from center (in)	Deflection at needle (in)
6	0.00307
5	0.00135
4	0.00046
3	0.00008
2	0

Table 7 - Record Deflection Results from SolidWorks Simulation

8.3 Arm Assembly

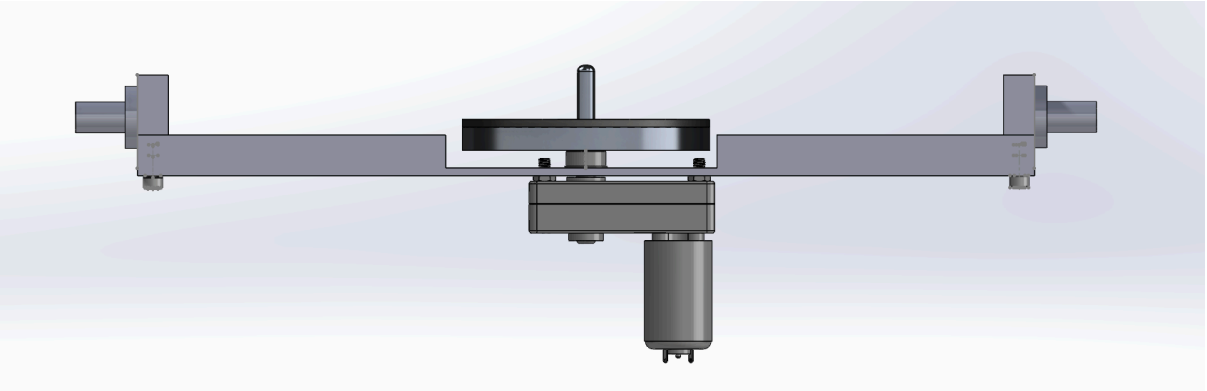


Figure 18 - Prototype Arm Assembly

Our final arm design consists of a fiberglass U-Bar frame, 2 aluminum mounting blocks, the platter motor, the top and bottom platters, and a bearing for the motor. The entire assembly is held together by black oxide bolts. Because of the robustness of the fiberglass, and the low loads on the entire structure, we analyzed the stresses on our fasteners, identifying the as the most probable sources of structural failure.

We conducted two simulations - one where we put 3 pounds of force on our arm shaft. The total assembly weight that is loaded onto the arm is slightly under 3 pounds. Our results yielded that we achieved a factor of safety (FoS) of approximately 18. This illustrates that there is still room to take material of for future products. The simulation is shown in Figure 18 below:

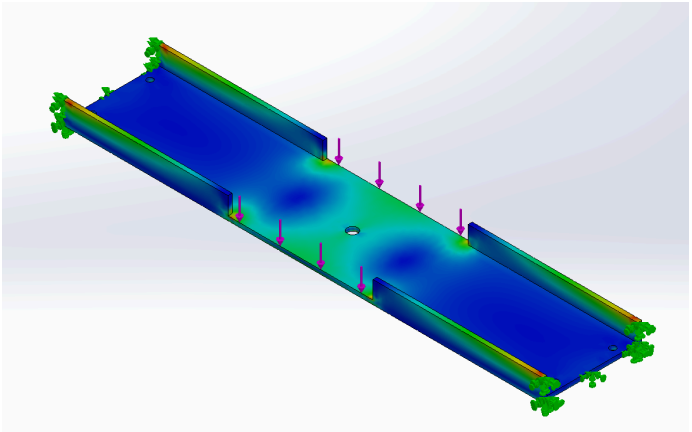


Figure 19 - Arm Shaft Simulation

We also tested our bolts that are attached to our servo that flips the record. We were slightly worried about these screws as they are undergoing both bending and tensile forces. We ran a quick simulation study on SolidWorks to address these concerns.

Our servo attachment bolts are loaded in bending and tension with 1.5 pounds.

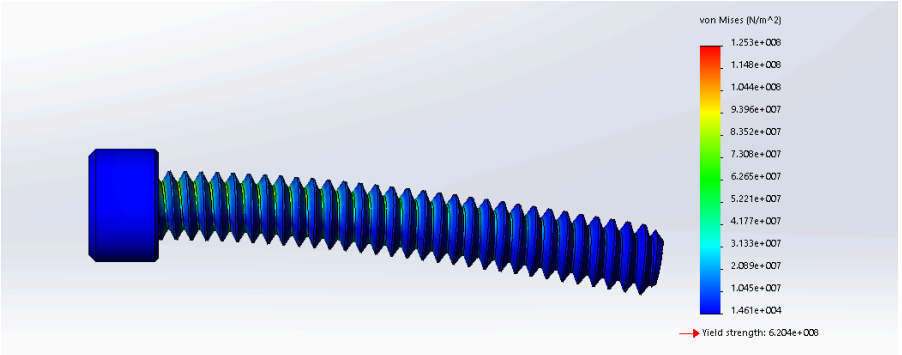


Figure 20 - Servo Screw in Bending

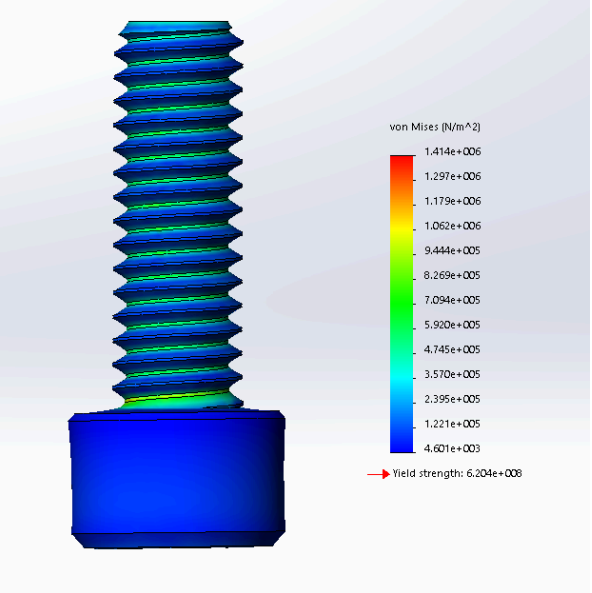


Figure 21 - Servo Screw in Tension

From the study, we saw that we had very high FoS with our screw in tension with a factor of safety of 418. However, our screw in bending had a much lower FoS with 4.8. As expected the lowest FoS we have is the bolt under the most stress. However the FoS is still well over our safe limit.

8.4 Base Weight Requirement

A simple moment balance of our system shows that the base needs to weigh 5.4 lb under the assumption that the needle and arm are located as far as possible from the center of the system, and the arm weighs 3 lb.

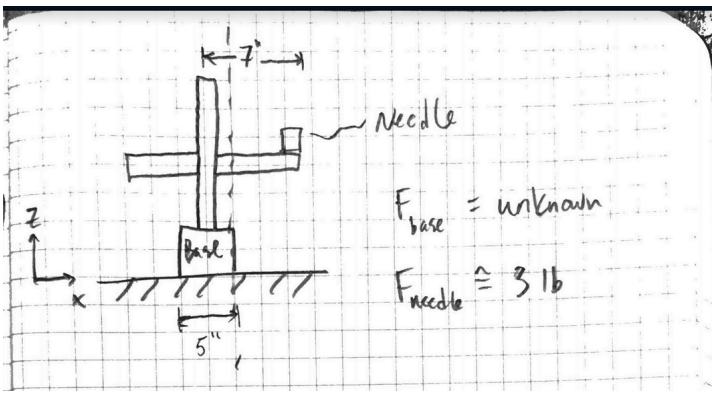


Figure 22 - Base Weight Calculations

Hence, we will use a 6 lb base made of a hollow, wooden cylinder secured to an aluminum cylinder (to house the electronics). Including metal in the base is the best design choice to meet the weight requirement while staying aesthetically pleasing.

8.5 Wood Selection

After modeling half of the wooden, vertical ring with balsa wood (E = ~48.7 MPa), there was shown to be a factor of safety of approximately 10. Clearly any higher quality selection of lumber will be more than enough to use the vertical ring to carry the device without adding an uncomfortable amount of weight (e.g. walnut wood: E = ~11.59 GPa). We ended up using Purple Heart, which has an elastic modulus of 20.26 GPa.

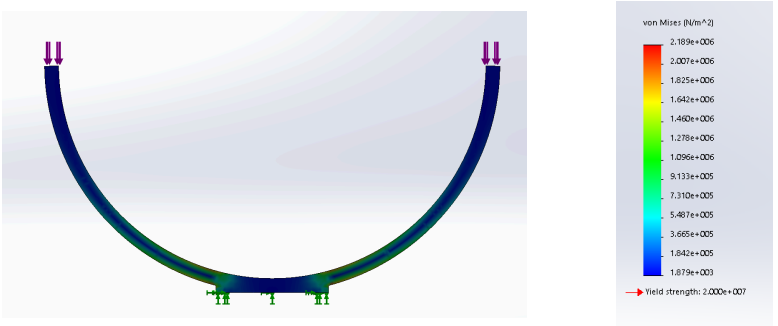


Figure 23 - Wood Stress Simulation

8.6 Failure Modes and Effects Analysis (FMEA)

We identified potential failure modes in our system and conducted a risk assessment on each failure mode and attempted to come up with potential mitigation plans moving forward to prevent these from occuring. Our FMEA Table is shown below.

Function	Failure Mode(s)	Effects	S	Causes	O	Current Control	D	RPN	Recommended Actions
Flip	Unalignment	Damage to Record Poor quality	8	Motor or Control Failure Damage to Mechanism	7	Motor Encoders	8	448	PID Controller
	Flip doesn't work	No Music Played	9	Error in Detection or Sensor Not enough Torque	2	Logic in Code	2	36	Break Statements, Better Sensors
	Detection of end of Record	Damages Needle Rest of system doesn't work	7	Sensor Detection	4	Motor Position / Encoders	5	140	Force Sensor on Needle
	Record Falls Out	Total System Failure Damage to the Record	9	Failure of Clamp	2	Snap Mechanism to lock Record	3	54	Keyed Shaft Connecting Platters to lock in, Adding rubber on top of Platters to increase Frictional Coefficient
Record Spin	Incorrect Rotational Speed (33RPM)	Poor Music Quality Potential Damages to Record	7	Motor Controls	2	Motor Encoders	3	42	PID Controller
	Platters out of Sync	Damage to Record	6	Failure of Clamp Mechanism	2	Shaft Mechanism to connect Platters	3	36	Keyed Shaft Connecting Platters to lock in, Adding rubber on top of Platters to increase Frictional Coefficient
Controls	Doesn't respond to Sensors	Total System Failure Damage to the Record	6	Sensor Detection and Errors	4	Sensors	5	120	Break Statements, Logic in Code and Better Sensors
	Doesn't respond to Inputs	Poor User Experience (UX)	6	Sensing Failures	2	Micro-controller	7	84	Utilize Button Press Operations
Structural	Bottom Arm Collapses or Fails	Damage to record Failure to play	9	Too much Weight Weak Design (Low FOS)	1	High FOS Design	4	36	Re-design Bottom Arm
	Globe Collapses	Total System Failure Record Damage	9	Too much Weight Weak Design (Low FOS)	1	High FOS Design	4	36	Re-design Globe Structure or Increase Thickness of Wood
	Instability	Imbalance / Tip Over Damage to System	7	Vibrations from Record Environment	4	Weight in Base to Stabilize	6	168	Vibrational Dampner, Re-design Weight Distribution of Globe to stabilize

Table 8 - FMEA

In our FMEA Table, we found 11 main potential failure modes in our system and categorized them into 4 primary functions: Flip, Record Spinning, Controls and Structural. Out of these failure modes, we found computed the Risk Priority Number (RPN) and found our 3 most likely failure modes - unalignment during our flip, detection of the end of record and instability in our structure.

Unalignment

Unalignment during the flip can occur due to the motor or controls failure or any damage to the mechanism. This would cause a decrease in the audio quality of the record. Our mitigation plan for this would be to implement a PID controller to tune and ensure the record is level. We can also mount an additional sensor on the arm to monitor the level and integrate those readings with the PID controller to ensure any environment or vibrations do not affect the alignment of our record.

Detection of the End of Record

One potentially large failure mode is the failure to identify that one side of the record has finished playing. This would cause the rest of our system to not work as it would not respond. Our current solution is to utilize motor encoder positions for standardized record players and tune it to those values. However, our mitigan plan is to add a force sensor to our needle. This would largely increase the accuracy of determining whether the record has finished playing as the grooves at the end exert significantly less force that we can detect with our sensor to determine that the side is done.

Instability

Anther large failure mode is instability in our system. Since we have a globe design, any vibrational and environment effects could cause our system to tip over and become imbalanced. Our mitigation plan for this would be to add vibration dampeners to our system and to add additional weight to our base so that our center of mass becomes lower which would make it harder to tip over.

8.7 Design for Environment

Our product is meant to be a long term decorative fixture as well as an electronic device. The ring structure is made of wood, the arm of fiberglass, the needle mount of aluminum, and the rest of plastic. The turntable is meant to stay in a stable, indoor location throughout its whole lifetime.. In the final product the wood would be oiled and covered in a protective lacquer to avoid any warping or damage due

to change in temperature or humidity. All other components should stay intact throughout its whole lifecycle. Since the device is meant to run for at least 40 minutes (the run time of an entire record) we would have to take more time in ensuring the microcontroller is properly cooled to avoid overheating.

As mentioned above the most important process for ensuring the product is able to survive its environment is to take time to treat and cover the wood. The rings are the supporting structure for the entire system and they must be taken care of. The wood treatment would also add to the overall style of the product and ensure it is as high quality as possible.

8.8 Manufacturing and Assembly Techniques

Our product is not meant for mass production. Each model would be hand crafted to ensure it is unique and up to standards. That being said, there can still be a methodical approach to manufacturing.

Bill of Materials (BOM):

Technics tone arm, 18" x 48" x ¾" sheet of wood, 2" wide fiberglass u channel, 3" x ¾" x 1" aluminum stock, 2 DC motors with encoders, 2 servo motors, a microcontroller, and PLA plastic.

Manufacturing and Assembly of Parts:

Step 1: Wooden Rings ($25 + wood price)

Using a vacuum wood router cut both rings and the base circles out of the wooden sheet. The router can also cut the divet where the needle mount is placed. Then drill two holes on opposite sides of the rings, on the same axis to fit the arm shafts into. Make sure to step up in drill size and not attempt to take the full hole diameter at once.

Step 2: Needle Mount ($25)

Using a CNC create the needle mount. This piece needs the tightest tolerances to ensure that the tonearm and needle are as level as possible. You will need to CNC both faces so take care to zero each time you switch faces on the stock.

Step 3: Record Arm ($10)

Cut a 400mm length of the fiberglass u-channel. Make sure to use a cold-blade saw to capture all the fiberglass particulate when cutting because it is very dangerous to breathe in. Then use a mill to drill holes for the DC motor and shaft mounts.

Step 4: Platters ($15)

3D print the top and bottom Platters. Because of the nature of 3D printing, we need to make sure to avoid fine threads as the plastic can be rubbed away each time the platters are threaded on and off. If necessary use a tap and die to clean up the threads on each piece.

Step 5: Ring Assembly

First wood glue the vertical bottom ring to one of the circular base pieces. Then drill pilot holes for screws on the vertical bottom ring. Next attach L brackets to the vertical ring using self threading wood screws. Next place the horizontal ring top face down and drill pilot holes for the wood screws. Place the vertical ring with L brackets onto the horizontal ring and fasten them down with wood screws. Finally set the assembly upright and glue the top vertical ring onto the horizontal ring.

Step 6: Final Assembly

Place the fiberglass arm into the wooden ring structure. Then fasten the needle mount onto the wooden ring using adhesive or wood screws. Mount the motors onto the needle mount and arm. Then place the platters onto the motor.

Overall the product manufacturing cost is around $75 including materials and machinist cost. The wood used for the prototype, purple heart, cost around $75. This gives us a total manufacturing cost of around $150, which would justify a final price range over $300.

9. Final Prototype Description

Our goal for the final prototype was to have a fully functioning record player. This record player would play one side of the record, remove the needle, then flip the record and play the other side. This prototype was manufactured using wood for the rings and fiberglass for record holding arm.

The wood for the rings was routed purpleheart. Wood glue and L brackets were used to hold the pieces together. The arm was a fiberglass U that connected to the rings with machined aluminum inserts. The record was held in place using 3D printed platters. These platters were threaded, allowing the user to clamp the record in place. The needle was connected to the ring by a CNC-ed aluminum piece. The pieces used to rotate and lift the needle were also 3D printed.

To automate our design, we used two servos and two DC motors with encoders. The arm flip was controlled by the first servo and was programmed to flip 180 degrees. The second servo was used to rotate a piece that would press down on the back of the needle arm, lifting it. The first DC motor was used to spin the record. Speed control was used to ensure that it would run at the desired 33 RPM. Finally, the second DC motor was used to rotate a piece that could move the lifted needle on or off the record.

For our demonstration, we wanted to be able to flip the record at will, so we had the flip be activated by a button press rather than automatically. At the first press of the button, the record would begin spinning and the needle would lift up, move to the edge of the record, and set down. We hooked the needle up to a speaker system, and the prototype was able to play the record. Once the needle was moved to the end of the record, the button could be pressed again. This would cause the needle to be lifted up and returned to the rest position. The record would then stop rotating, flip 180 degrees, and start spinning in the opposite direction. Finally, the needle would return to the edge of the record and begin playing the second side. After the second side, the button would activate a return to the start state - the needle in the rest position and the record right side up.

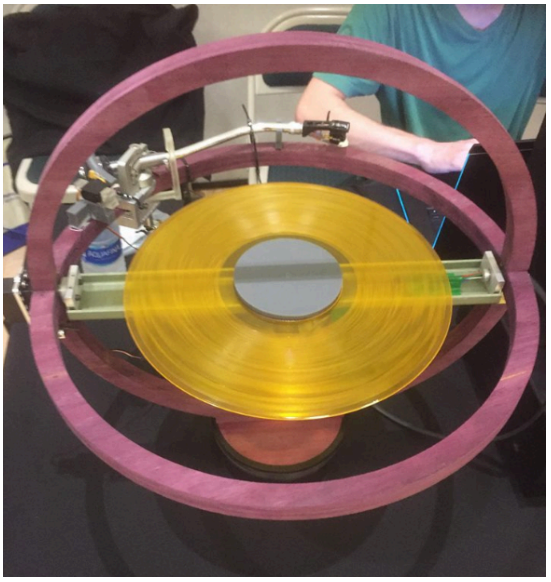


Figure 24 - Testing Rig for Final Prototype

Video Link - https://www.youtube.com/watch?v=fz9DSJixtbg

To test our prototype, we focussed on four key requirements - the time taken to flip the record, the levelness of the record, the needle positioning, and the sound quality. Our tests and results are shown and analyzed in the sections below:

Time Taken

To measure the time taken to flip, we used a stopwatch to measure the time it took from the press of the button to the moment the needle was back on the record. To minimize human error, we performed ten trials and took the average of them. We also conducted a survey on 50 users with various times to flip the record and actuate our needle to determine which combination had the greatest 'wow-factor' that drew the users' gaze towards our device. We utilized values of 2, 5, 7.5 and 10 seconds for each of the Needle Actuation and Flip Time.

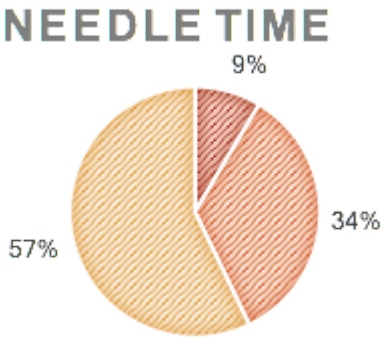


Chart 1 - User Survey for Needle Time

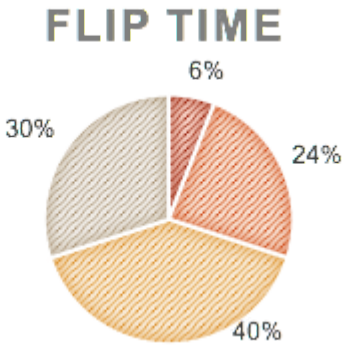


Chart 2 - User Survey for Flip Time

Trial	Flip Time (s)
1	7.69
2	7.40
3	7.50
4	7.49
5	7.56
6	7.46
7	7.58
8	7.53
9	7.60
10	7.48

Table 9 - Flip Time Data Collection

In the pie charts, red represents 2 seconds, orange represents 5 seconds, yellow represents 7.5 seconds,and grey represents 10 seconds. We can see that 7.5 seconds seemed to be the most popular for both the time taken to actuate the needle and time taken to flip the record. We tuned our flip time results to this value shown in Table 9 above.

From this data, we found an average flip time of 7.52 seconds with a standard deviation of 0.08 seconds. We compared this to manually flipping a record on a normal turntable and found that that took around 10-15 seconds, not including the time taken to walk over and back from the record player. Thus, we determined that our record was not only slightly faster than manually flipping the record but also utilized an aesthetic method to flip the record that drew user's in and created a 'wow-factor'.

Levelness of Record

One critical requirement in our design is the levelness of our record. This is of pivotal and paramount importance as if the record is not straight the audio quality of the turntable decreases significantly as well as it could throw the balance of the turntable and cause some structural damage or damage to the Vinyl record.

To address this concern, we utilized a digital level and measured the amount rotated after one flip. The results are shown in Figure 25 below.

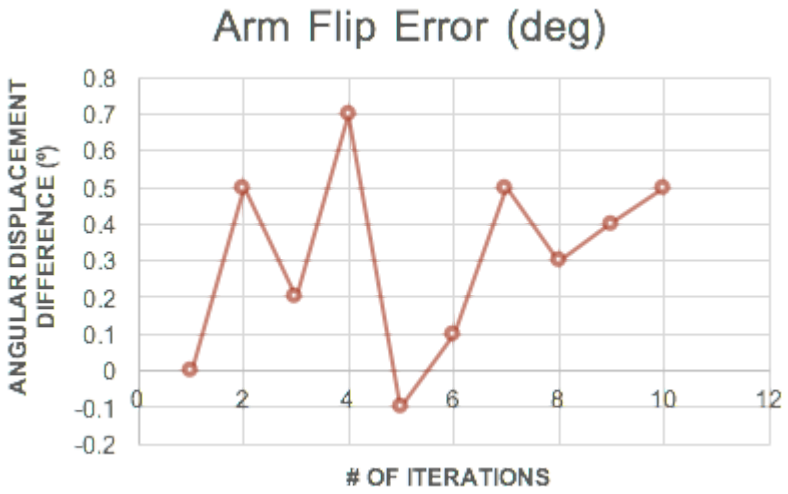


Figure 25 - Arm Flip Error

The graph above illustrates the difference between the amount rotated and a 180° rotation i.e. showing the overshoot or undershoot from a perfectly horizontal rotation. We can see that there is some error between these two values. However, the variation is always within very small and negligible and does not impact the audio quality of the record significantly or affect the balance of the turntable. Our conclusion from the levelness testing and analysis is for future designs, we would want to utilize a DC motor with encoder - instead of a servo - to minimize the error in rotation with a PID controller. This will allow us to tune the values instead of rely on the build in integral value within servos.

Needle Positioning

To ensure that the needle would always go to the right place, we set encoder values for the rest position, record start position, and record end position. To avoid encoder rollover issues, we set the rest position at tick 20,000. We then manually calibrated the record start and end values by placing the needle in the correct place and reading the encoder value. The below table shows the values we used.

Needle Position	Encoder Value

Rest	20,000
Start of Record	20,450
End of Record	21,069

Table 10 - Tuned DC Motor Encoder Positions

Sound Quality

In addition to qualitative testing, we wanted to see if the sound quality of our record player was comparable to normal record players. Since sound quality is subjective, this is something we had to just examine by ear. The quality of a record player is influenced by a number of things, most notably the needle quality, the record levelness and stability, and the rotation speed. Our needle was taken from a high quality record player, so that was likely not an issue, though it is possible that it got slightly damaged during assembly and testing. With our speed control program, we were able to ensure 33 RPM so that was not an issue either.

We did run into issues with our 3D printed platters. The bottom platter was fairly warped, leading to a noticeable wobble of the record. Therefore, even though the platters were level, the record was not. This led to a noticeable amount of skipping on either side of the record, especially at the beginning of each side where the needle is at the edge. This could also be impacted by the records we chose, which had some nicks and scratches. However, the actual sound quality of the record was quite good, easily comparable to other record players. We think that with more level 3D printed platters this skipping problem could be remedied. If not, CNC-ed platters could be a better, more precise solution.

Successes / Failures of Final Prototype

Overall, our final prototype was a major success. We were able to achieve all the functionality that we wanted. The prototype could play both sides of the record at the press of a button. All of the subsystems worked well and integrated with each other without issue. The design was able to play a full record with reasonably good sound quality. A further iteration would focus on polishing and tweaking rather than redesigning.

However, our prototype was still rough around the edges in several areas. The most notable thing we would want to fix is the record wobble. We were going to attempt to fix this by printing a new platter, but ran out of time. If 3D printing proved too unreliable for this purpose, we might have to look into difference materials or manufacturing methods. Second, we had issues with the needle placement encoder. It would often overshoot, meaning that we would have to constantly reset the arduino in the rest position to ensure that it would always place the needle in the right spot. This was likely an issue with the cheap motor and encoder that we bought, and could likely be fixed by just buying a more reliable encoder. Finally, we would want to improve the aesthetic design of our product. The main issue was that all the cables and electronics were on the outside and clearly visible. For a product that is designed to be the centerpiece of a room, this is not acceptable. For a next iteration, we would want all of the electronics to be hidden in the base with a button inlaid in the horizontal ring or base that could activate it. Ideally, all the cables would run down the rings with as little visibility as possible.

10. Conclusions

As a team, we learned several things. First and foremost, we learned that electronics will often have issues and time and money should be allocated accordingly. During the building of our prototypes, we had many issues with servos, encoders, and arduinos. During prototype 2, the servos we were using burned out and we had to use another one that we found that barely had enough torque to flip it. For the final prototype, we realized that the flip servo we were going to use only turned 120 degrees and had to again scrounge for a replacement. The encoder we used to the needle was extremely unreliable and had to be constantly reset to stop it from overshooting. Finally, due to a short our arduino mega was fried and we had to spend time fixing it. Considering our high budget, we should have just bought extra components for important pieces and spent money on higher quality parts.

As for our custom parts, they were largely very successful. The main issue we had was with the very hard wood we used. We picked purpleheart for its good properties and aesthetic. However these properties made it difficult to machine, and we had heat and cracking problems. Now that we know the quirks of this wood, we would be more careful when trying to cut and drill it. Hopefully this would lead to no cracking.

Throughout the project, we learned how easy it was to save weight, mainly on the arm. For the first prototype we used a hollow aluminum beam and large 3D printed platters. This assembly was very heavy. For prototype two, cut a large amount of weight from the aluminum beam by turning it into a U channel. We also swapped the 3D printed platters out with much smaller aluminum platters. Finally, we added the spinning motor, which was way overpowered for this application. So while we saved weight in some areas, it was still very heavy. For the final prototype, we drastically reduced the weight of every part. The DC motor we used was much smaller and lighter. The platters were 3D printed but much smaller than those used in prototype one. The aluminum arm was swapped out for a very light fiberglass arm. The result was something still strong but a fraction of the former weight and therefore much easier to flip.

Additionally, our planning could have been better. Admittedly some of this was unavoidable due to the large amount of work due at the end of the semester. However, we ran into several issues near the end of assembly and it would have been ideal to have more time to work them out. If we were given the chance to repeat this project, we would try to have the prototype finished at least a few days before the expo so that we would have time to fix any issues that would arise.

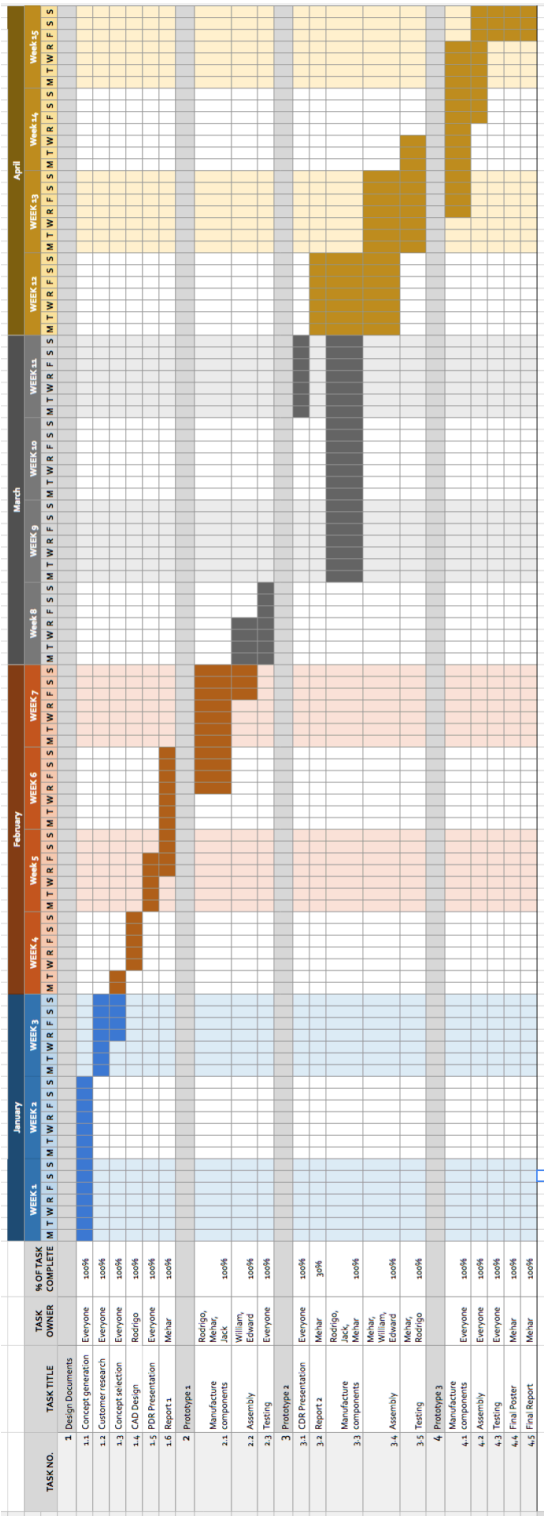
There are several issues that we left unresolved. First was the platter wobbling. The 3D printed part was warped, causing the record to sway while spinning. This led to the record skipping fairly often. This hurt the sound quality and had the possibility of damaging the record and needle. Next, the needle encoder did not work correctly and would cause the needle placement to overshoot and start playing a bit into the second side of the record. We solved this by resetting the arduino before the needle would move onto the record each time, but obviously this is a very makeshift solution and would need to be remedied. Finally, the aesthetic design was very poor due to the mess of wires and exposed electronics.

For a future team continuing this project, I would recommend focusing on improving the performance and aesthetic design. For this to be an actual product, it would need to be much more polished. The wobble of the record would need to be fixed first, as that was the biggest issue. This could be fixed by printing improved platters, or possible just going back to CNC'd aluminum. The encoder issue could be fixed by just buying a more reliable motor with encoder. Finally, the aesthetics could be improved by hiding the wires in the rings and arm and putting the electronics in the base. Additionally, the needle assembly could be redesigned with aesthetics in mind.

11. Future Tasks and Conclusions

11.1 Gantt Chart

Our Gantt Chart is shown below. It highlights the timeline for each of our key components of our system. Our schedule is to finish the system one week before the end of the semester and design exposition so that we can test our entire system for reliability.



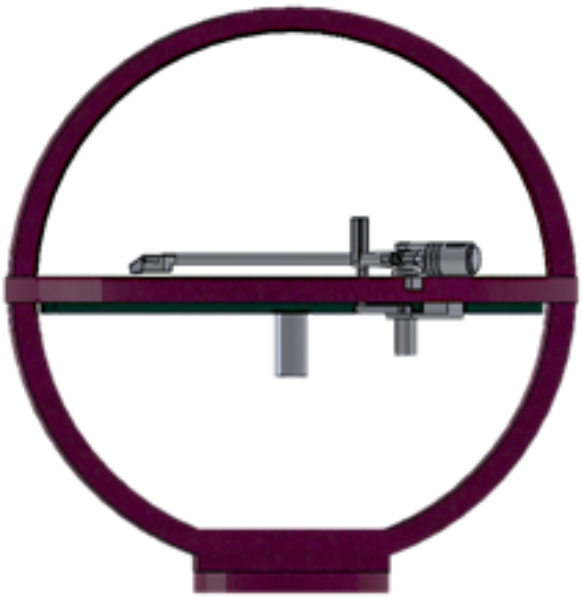
12. References

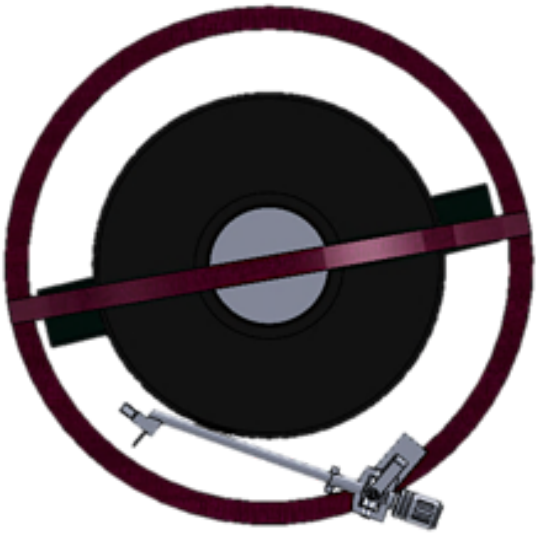
1. https://www.planetofsoundonline.com/pages/yes-turntables-are-back
2. https://uturnaudio.com/blogs/uturn/our-manufacturing-process
3. http://www.goldminemag.com/articles/welcome-to-jerrys-records-paradise-for-vinyl-record-lovers
4. https://www.alignproductionsystems.com/a_solution/industrial-heavy-duty-turntables/

13. Appendices

CAD Models

The following images depict different views of our CAD Models such as a side and top views



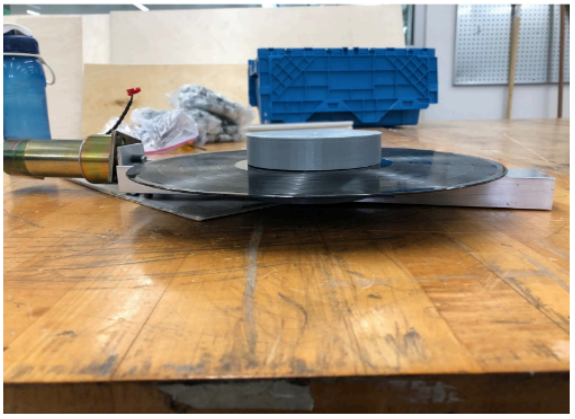


Deflection Analysis



Prototype I Component Images



Microcontroller Code

Rotating Needle

```
#define encoder0PinA  2
#define encoder0PinB  3

volatile unsigned int encoder0Pos = 20000;

void setup() {
  pinMode(encoder0PinA, INPUT);
  pinMode(encoder0PinB, INPUT);
  pinMode(5, OUTPUT);
  pinMode(6, OUTPUT);
  pinMode(7, OUTPUT);
  // encoder pin on interrupt 0 (pin 2)
  attachInterrupt(digitalPinToInterrupt(encoder0PinA), doEncoderA, CHANGE);

  // encoder pin on interrupt 1 (pin 3)
  attachInterrupt(digitalPinToInterrupt(encoder0PinB), doEncoderB, CHANGE);
```

```
  Serial.begin (9600);
}

void loop() {
  //Do stuff here
  Serial.println (encoder0Pos);
  if(encoder0Pos <20050)
  {
    digitalWrite(5, !LOW);
    digitalWrite(6, !LOW);
    digitalWrite(7, !LOW);
  }

  if(encoder0Pos > 20430 && encoder0Pos < 21200)
  {
    Serial.println("on record");
    digitalWrite(5,!HIGH);
    digitalWrite(6, !LOW);
    digitalWrite(7, !LOW);
  }
  if (encoder0Pos > 21200)
  {
    digitalWrite(5,!LOW);
    digitalWrite(6, !HIGH);
    digitalWrite(7, !LOW);
  }
  if (encoder0Pos >20050 && encoder0Pos <20430)
  {
    digitalWrite(5,!HIGH);
    digitalWrite(6, !HIGH);
    digitalWrite(7, !LOW);
  }
}

void doEncoderA() {
  // look for a low-to-high on channel A
  if (digitalRead(encoder0PinA) == HIGH) {

    // check channel B to see which way encoder is turning
    if (digitalRead(encoder0PinB) == LOW) {
      encoder0Pos = encoder0Pos + 1;         // CW
    }
    else {
      encoder0Pos = encoder0Pos - 1;         // CCW
    }
  }

  else   // must be a high-to-low edge on channel A
  {
```

```
    // check channel B to see which way encoder is turning
    if (digitalRead(encoder0PinB) == HIGH) {
      encoder0Pos = encoder0Pos + 1;         // CW
    }
    else {
      encoder0Pos = encoder0Pos - 1;         // CCW
    }
  }


}

void doEncoderB() {
  // look for a low-to-high on channel B
  if (digitalRead(encoder0PinB) == HIGH) {

    // check channel A to see which way encoder is turning
    if (digitalRead(encoder0PinA) == HIGH) {
      encoder0Pos = encoder0Pos + 1;         // CW
    }
    else {
      encoder0Pos = encoder0Pos - 1;         // CCW
    }
  }

  // Look for a high-to-low on channel B

  else {
    // check channel B to see which way encoder is turning
    if (digitalRead(encoder0PinA) == LOW) {
      encoder0Pos = encoder0Pos + 1;         // CW
    }
    else {
      encoder0Pos = encoder0Pos - 1;         // CCW
    }
  }
}
```

Lifting Servo, End Detection, etc. (Everything else)

```
#include <Wire.h>
#include <Adafruit_MotorShield.h>
#include <Servo.h>

long AlbumValue = 1000000; //time for each album in milliseconds.
```

```
#define RecordSpinEncoder  2

unsigned long active_state = -1;
#define FLIPPING_A 1
#define FLIPPING_B 2
#define NEEDLE_ON 10
#define NEEDLE_OFF 11
#define NEEDLE_END 12
#define RUNNING 20
#define RUNNING_REV 21
#define STOP 22
#define FLIP 30


volatile unsigned long RecordSpinEncoderPosition = 0;
volatile  int recordSpinMotorSpeed;
volatile float difference;
volatile unsigned long currTime;
long lastRecordSpinPosition;


Adafruit_MotorShield AFMS = Adafruit_MotorShield();


Adafruit_DCMotor *RecordSpinMotor = AFMS.getMotor(3);
Adafruit_DCMotor *NeedlePositionMotor = AFMS.getMotor(4);

Servo FlipServo;
Servo LiftServo;

bool needleLift = false;
bool flip = false;

void setup() {
  // put your setup code here, to run once:
  pinMode(5, INPUT_PULLUP);
  pinMode(6, INPUT_PULLUP);
  pinMode(53, INPUT);

  attachInterrupt(digitalPinToInterrupt(2), recordSpin, CHANGE);

  AFMS.begin();

  FlipServo.attach(10);
  LiftServo.attach(9);
  NeedlePositionMotor->setSpeed(35);
  RecordSpinMotor->setSpeed(50);
  Serial.begin(9600);
```

```
  FlipServo.write(0);
  LiftServo.write(120);
  active_state = NEEDLE_ON;
  delay(5000);
}

void loop(){
  switch(active_state){
  case NEEDLE_ON:
  needleOnLoop();
  break;

  case NEEDLE_END:
  needleEndAlgorithm();
  break;

  case RUNNING:
 // if(millis()> AlbumValue)
 // {
 //   active_state=NEEDLE_OFF;
 // }
  RecordSpinAlgorithm();
  if(digitalRead(53)==HIGH){
  Serial.println(millis());
  active_state = NEEDLE_OFF;
  }
  break;

  case NEEDLE_OFF:
  if(!needleLift){ //lifts needle on 1st time)

     liftNeedle();
     needleLift = true;
     currTime = millis();
   }
   delay(1000);
  needleOffAlgorithm();
  break;

  case FLIP:
  RecordSpinMotor->run(RELEASE);
  delay(1000);
  int k = 0;
  if(!flip){
    for (k = 0; k <= 170; k += 1) { // goes from 0 degrees to 180 degrees
    // in steps of 1 degree
    FlipServo.write(k);              // tell servo to go to position in variable 'pos'
    delay(15);                       // waits 15ms for the servo to reach the position
  }
```

```
  delay(1000);
    flip = true;

  }
  else {
    for (k = 170; k >= 0; k -= 1) { // goes from 180 degrees to 0 degrees
    FlipServo.write(k);              // tell servo to go to position in variable 'pos'
    delay(15);                       // waits 15ms for the servo to reach the position
  }
  delay(1000);
  flip = false;
  }
  active_state = RUNNING;
  break;
 }
}
void needleOnLoop()
{
  static unsigned long chkrn = 0;
  if(chkrn%2){
    if(!needleLift){
      liftNeedle();
      needleLift = true;
    }
  //  Serial.println("state1");
    needleOnAlgorithm();
  } else{
    RecordSpinAlgorithm();
   // Serial.println("state2");
  }
  //Serial.println(chkrn);
  chkrn++;

}
void needleOnAlgorithm() {
  // put your main code here, to run repeatedly:
  Serial.print(digitalRead(45));
  Serial.print("    ");
  Serial.println(digitalRead(47));
  LiftServo.write(93);
  if((digitalRead(45) == !LOW && digitalRead(47) == !LOW) || (digitalRead(45) == !HIGH &&
digitalRead(47) == !HIGH))
    {
     NeedlePositionMotor->run(FORWARD);
    } else{
      Serial.println("stop motor");
      NeedlePositionMotor->run(RELEASE);
      NeedlePositionMotor->setSpeed(35);
      delay(1000);
```

```
    int pos;
    for (pos = 93; pos <= 120; pos += 1) { // goes from 0 degrees to 180 degrees
   // in steps of 1 degree
   LiftServo.write(pos);              // tell servo to go to position in variable 'pos'
   delay(120);                       // waits 15ms for the servo to reach the position
  }
   needleLift = false;
    active_state = NEEDLE_END;
    delay(2000); //remember to comment out
   }
}

void needleEndAlgorithm(){
    if((digitalRead(45) == !LOW && digitalRead(47) == !HIGH))
   {
     NeedlePositionMotor->run(RELEASE);
    NeedlePositionMotor->setSpeed(35);
    active_state = RUNNING;
    delay(2000); //remember to comment out

   } else{
    //Serial.println("stop motor");
    NeedlePositionMotor->run(FORWARD);
   }
    //delay(2000); //remember to comment out

}

void needleOffAlgorithm(){
  if((digitalRead(49) == !HIGH) || millis()-currTime > 3000)
   {
    Serial.println("lower needle at home");
    NeedlePositionMotor->run(RELEASE);

    int i =93;
    for (i = 93; i <= 120; i += 1) { // goes from 0 degrees to 180 degrees
   // in steps of 1 degree
       LiftServo.write(i);              // tell servo to go to position in variable 'pos'
      delay(120);                       // waits 15ms for the servo to reach the position
    }
   needleLift = false;
    active_state = FLIP;
    delay(2000); //remember to comment out

   }
   else{
    NeedlePositionMotor->setSpeed(33);
   NeedlePositionMotor->run(BACKWARD);
  }
```

```
}

long lastChk_loop2 = -1;
#define DELAY_LOOP2 50
void RecordSpinAlgorithm(){

  static long currTime;
  currTime = millis();

  if((currTime - lastChk_loop2) > DELAY_LOOP2){
      // put your main code here, to run repeatedly:
      if(!flip)
     RecordSpinMotor->run(FORWARD);
     else RecordSpinMotor->run(BACKWARD);
      // set at end
     //delay(1000);
     difference = 1000.0 * ((float)(RecordSpinEncoderPosition - lastRecordSpinPosition)) / ((float)
(currTime - lastChk_loop2));
     if((difference-390.0) > 10.0)
     {
      recordSpinMotorSpeed=recordSpinMotorSpeed-1;
     }
     if((difference-390.0) < -5.0)
     {
      recordSpinMotorSpeed=recordSpinMotorSpeed+1;
     }

     RecordSpinMotor->setSpeed(42);
    // Serial.print("speed ");
    // Serial.println(recordSpinMotorSpeed);
    // Serial.print("difference ");
    // Serial.println(difference);
    // Serial.println(RecordSpinEncoderPosition);
     lastChk_loop2 = currTime;
     lastRecordSpinPosition = RecordSpinEncoderPosition;
  }
}




//record spin interrupt
void recordSpin() {
  RecordSpinEncoderPosition++;
}

void liftNeedle(){
```

```
  int pos;
  for (pos = 120; pos >= 93; pos -= 1) { // goes from 180 degrees to 0 degrees
    LiftServo.write(pos);              // tell servo to go to position in variable 'pos'
    delay(80);                         // waits 15ms for the servo to reach the position
  }
}
```